

Characterization of microbulk detectors in argon- and neon-based mixtures

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Abstract

A recent Micromegas manufacturing technique, so called Microbulk, has been developed, improving the uniformity and stability of this kind of detectors. Excellent energy resolutions have been obtained, reaching values as low as 11% FWHM at 5.9 keV in Ar+5%iC₄H₁₀. This detector has other advantages like its flexible structure, low material budget and high radio-purity. Two microbulk detectors with gaps of 50 and 25 μm have been characterized in argon- and neon-based mixtures with ethane, isobutane and cyclohexane. The results will be presented and discussed. The gain curves have been fitted to the Rose-Korff gain model and dependences of the electron mean free path and the threshold energy for ionization have been obtained. The possible relation between these two parameters and the energy resolution will be also discussed.

1 Introduction

Micromegas (for MICRO MESH Gaseous Structure) is a parallel-plate detector invented by I. Giomataris in 1995 [1]. It consists of a thin metallic grid (commonly called mesh) and an anode plane, separated by insulated pillars. Both structures define a small gap (between 20 and 300 μm), where primary electrons generated in the conversion volume are amplified, applying moderate voltages at the cathode and the mesh. This technology has proven to have many advantages like its high granularity, good energy and time resolution, easy construction, little mass and gain stability.

The first detectors were built by screwing two different frames: the anode plane and the metallic grid, under which the insulated pillars were electroformed. By applying voltages to both structures, the intense electric field pulled down the mesh and the flatness was thus defined by the height of the pillars, with an accuracy better than 10 μm . The good flatness and parallelism between the anode and the mesh was obtained only if the delicate operation of screwing was successful. To avoid this operation, two different technologies (called bulk [2] and microbulk [3, 4]) have been developed so that the readout plane and the mesh formed a single integrated structure.

In the microbulk technology, the raw material is a thin flexible polyimide foil with a thin copper layer on each side. The foil is glued on top of a rigid substrate that provides the support of the micro-structure and carries the anode strips or pixels. In the first step, a thin photoresistive film is laminated on top of the kapton foil and is insulated by UV light to produce the required mask. The copper is then removed by a standard lithographic process, generating the pattern of a thin mesh. The polyimide between the mesh and the readout plane is then etched and removed under the mesh holes, but it remains almost intact elsewhere [3].

The resulting detector has a more homogeneous amplification gap and a better mesh than the classical Micromegas, reducing the avalanche fluctuations and improving the energy resolution. There is also a reduction of the border regions, eliminating dead zones and allowing its application in imaging with x-rays or neutrons. Moreover, the detector is made of kapton and copper, two of the materials with the best levels of radiopurity. These materials define a level of contamination below PMTs[5]. The only possible drawbacks of this technique are its lack of robustness and the limited maximum size ($30 \times 30 \text{ cm}^2$), due to the actual

equipment. Nevertheless, the improved detectors have been applied in several experiments like nTOF [6], CAST [7] or NEXT[8, 9].

The microbulk technology shows the best energy resolution of MPGD detectors, as good as 11% FWHM at 5.9 keV in Ar+5%iC₄H₁₀, improving the values around 14% FWHM reached by proportional counters two decades ago [10]. The reference gas in tests was fixed by studies of that time, as a high gain and a good energy resolution was obtained. However, the improved performances of microbulk detectors give the opportunity to study in detail the influence of the gas mixture on these parameters and to verify the conclusions obtained with proportional counters. Moreover, if microbulk detectors could work at higher gains ($> 10^4$) keeping a good energy resolution, this technology could be used in sub-keV applications, like in Synchrotron Radiation and Dark Matter searches where the low energy threshold is crucial.

In this article, we present the performance of microbulk detectors in argon and neon-based mixtures. The detectors tested respectively have a gap size of 50 and 25 μm . The first gap is the more common used in the new microbulk detectors and the second one is expected to show better performances at high pressure gases [11]. In the second section, the setup and the procedure are described in detail. The features of microbulk detectors in argon- and neon-based mixtures with three different quenchers are described in sections three and four. Finally, we present the Rose-Korff gain model for Micromegas, the dependencies obtained for some gas parameters and we discuss the validity of this model and its possible relation with the energy resolution. We finish this report with some conclusions and an outlook of the actual developments.

2 Setup and procedure description

The vessel used in these tests (figure 1, left) was specifically designed to characterize a maximum of three micromegas detectors (not necessary microbulk) in the same gas conditions, with a maximum surface of $50 \times 50 \text{ mm}^2$. It consists of an aluminium box, with an internal volume of $60 \times 165 \times 30 \text{ mm}^3$ and a wall thickness of 8 mm. The chamber is equipped with two gas entrances to circulate the desired gas. Detectors are placed on a plastic support situated inside the vessel, which electrically isolates them from the inner walls. For each detector, there is a mesh frame screwed to the plastic plate, which is used as a drift cathode and defines a drift distance of 10 mm. The drift, mesh and anode voltages are respectively extracted by a high voltage (SHV) and two signal (BNC) feed-throughs for each detector. On the top cap of the chamber, several holes allow the calibration by x-ray sources situated outside. These holes are covered by an aluminized mylar films, that are scotched to the inner wall of the cap with kapton and create the gas-tightness of the vessel.

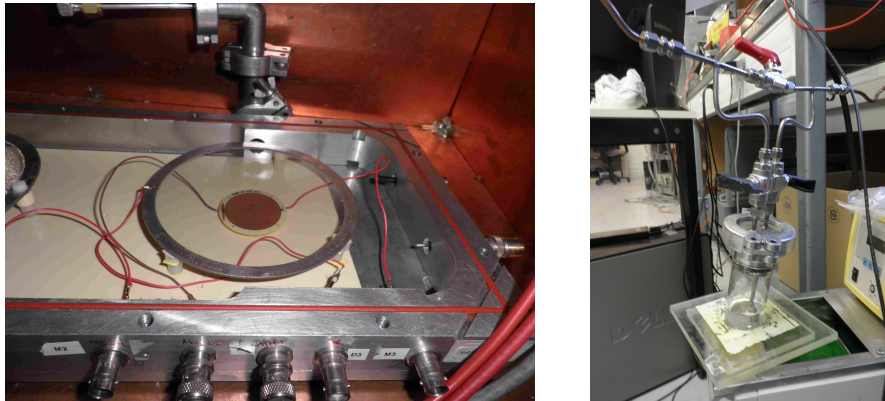


Figure 1: *Left: A view of one microbulk detector installed in the vessel. Right: A view of the gas setup used for the cyclohexane mixtures. The base gas is forced to pass by a glass vessel filled with the liquid quencher. The container is situated inside a refrigerator, shown opened under the vessel.*

During at least one hour, a flow of the desired mixture was circulated by the chamber. In the case of mixtures with cyclohexane, the base gas was forced to pass by a glass vessel, filled with this liquid quencher (figure 1, right). The gas concentration was defined by the liquid temperature, which was kept constant by a refrigerator in which the vessel was immersed. This temperature could not be higher than the ambient one

to avoid possible quencher condensations inside the vessel. For a temperature of 25°C, this condition fixes a maximum concentration of 11%.

The detectors were illuminated by an iron ^{55}Fe source (x-rays of 5.9 keV) keeping the same gas flow. The mesh voltage was typically varied from 200 to 600 V and the drift one from 280 to 5000 V, depending on the type of gas. Both voltages were powered independently by a CAEN N471A module. The avalanche induces a negative signal in the mesh, which is read out by an ORTEC 142C preamplifier. The preamplifier output was fed into an ORTEC 472A spectroscopy amplifier and subsequently into a multichannel analyzer AMPTEK MCA-8000A for spectra building. For reducing systematic errors, each spectrum has a minimum of 5×10^4 points.

Two microbulk detectors respectively with a gap size of 25 and 50 μm have been characterized. They have a circular shape (35 mm of diameter) and a single non-segmented anode. Their specific references are M50.70.35.04 and M25.50.25.09, which respectively correspond to a pitch distance of 70 and 50 μm and a hole diameter of 35 and 25 μm . These particular detectors have showed an energy resolution of 11.7% and 11.8% FWHM at 5.9 keV in Ar + 5% iC_4H_{10} , values which are close to the best value observed for microbulk detectors (11% FWHM).

3 Characterization in argon-based mixtures

The drift voltage was firstly varied in our tests for a fixed mesh voltage to obtain the electron transmission curve, that shows the mesh transparency to primary ionization. These curves are shown for the argon-isobutane case and both detectors in figure 2. Microbulk detectors show a plateau of maximum electron transmission for a wide range of ratios of drift-to-amplification fields. At higher drift fields, the mesh stops being transparent for the primary electrons generated in the conversion volume and both the gain and the energy resolution degrade. The specific maximum value for the ratio depends on the diffusion coefficient, being wider the plateau for higher quantities of the quencher. This fact is in agreement with the shorter plateaus observed in pure gases [13, 14] and the wider plateaus measured in gases with low diffusion coefficients [15].

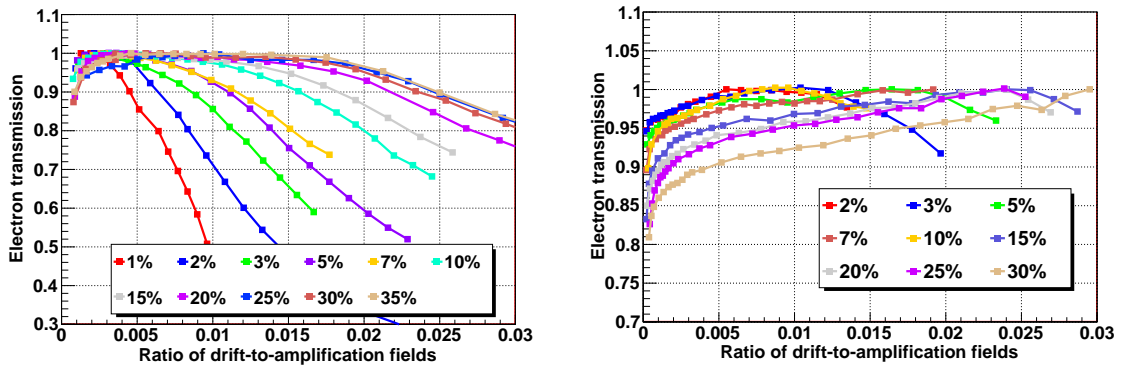


Figure 2: Dependence of the electron transmission with the ratio of drift-to-amplification fields for two microbulk detectors with gaps of 50 and 25 μm in argon-isobutane mixtures. The gain has been normalized to the maximum of each series. The percentage of each series corresponds to the isobutane concentration.

However, the detector of 25 μm -thickness gap does not show the same behaviour, as shown in figure 2 (right). For low isobutane concentrations, there is a short plateau of maximum mesh transparency but it starts at relative high drift field. At high isobutane concentrations, this plateau disappears and there is a steady increase of the detector gain with the drift field. This effect has been verified by other microbulk of the same gap, a hole pitch between 50 and 100 μm and a hole diameter between 20 and 30 μm . A possible explanation is that the mesh may not be completely transparent for electrons for the pitch and hole diameter considered. Indeed, the best values of the energy resolution are reached at low drift fields (figure 3, right).

The dependence of the energy resolution with the ratio of fields is shown in figure 3 for argon-isobutane mixtures. For a gap size of 50 μm , the energy resolution shows its best value for the same drift fields for

which the electron transmission is the optimum. There is also a dependence on the isobutane concentration. For values below 5%, the energy resolution is worse as not all the UV photons produced in the avalanche are absorbed [16]. For values between 5 and 7%, the energy resolution reaches its optimum and then degrades at higher isobutane concentrations. There is an increase of the gain fluctuations due to a higher proportion of scattering processes than ionization ones [17].

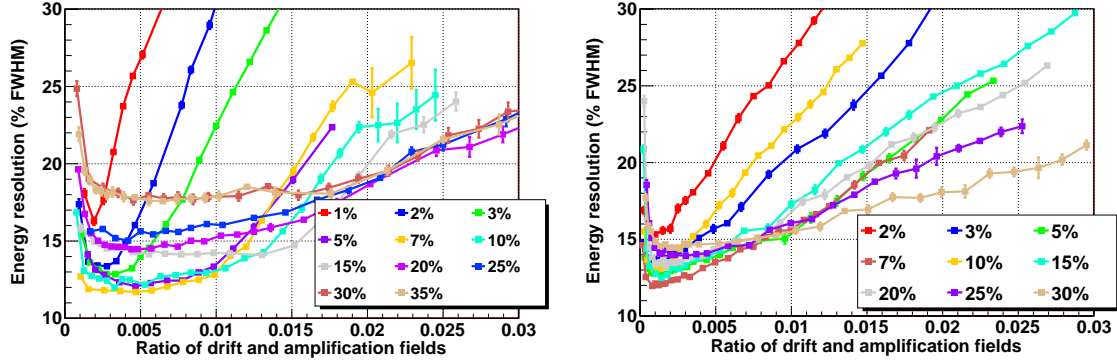


Figure 3: Dependence of the energy resolution with the ratio of drift-to-amplification fields for two microbulk detectors with gaps of 50 and 25 μm in argon-isobutane mixtures. The percentage of each series corresponds to the isobutane concentration.

In the case of the 25 μm -thickness-gap detector, the energy resolution reaches its best values for the lowest drift fields. This fact supports the hypothesis that the mesh is not totally transparent for electrons. There is also a dependence on the isobutane concentrations, but not so strong as for the former detector. The energy resolution degrades from 12% up to 14.5% FWHM when the isobutane concentration passes from 7% to 30%, which is less than the 19% FWHM measured with the 50 μm -thickness-gap detector.

The dependence of the peak position with the mesh voltage generates the gain curves, shown in figure 4 for argon-isobutane mixtures. The maximum gain before the spark limit is respectively 2×10^4 and 10^4 for the detectors with a gap size of 50 and 25 μm . This fact happens for all mixtures in the first case and only for isobutane concentrations over 10% for the second one. Apart from that, the gain curves for low quantities of isobutane show a deviation from the Rose and Korff gain model [18] at high amplification fields. This over-exponential behaviour is due to the low quencher concentrations, which cannot avoid the production of secondary avalanches by the UV photons generated in the primary avalanche [16].

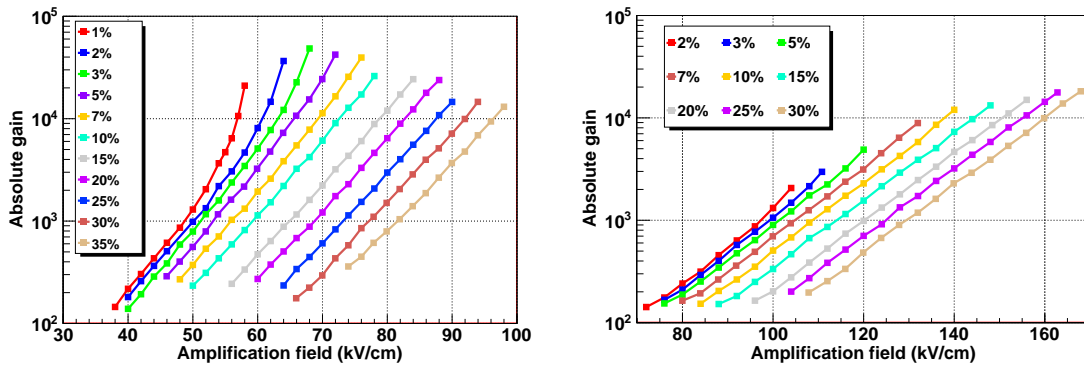


Figure 4: Dependence of the absolute gain with the amplification field for two microbulk detectors with gaps of 50 (left) and 25 μm (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.

The energy resolution has also a dependence with the amplification field (figure 5), and more specifically with the gain, which was already observed with proportional counters [10, 19]. At low gains, the energy

resolution degrades because the signal starts being comparable to the noise. At high gains, the resolution worsens due to the increase of the gain fluctuations. This effect disappears at high isobutane concentrations. However, the energy resolution is also worse, due to the larger gain fluctuations [17].

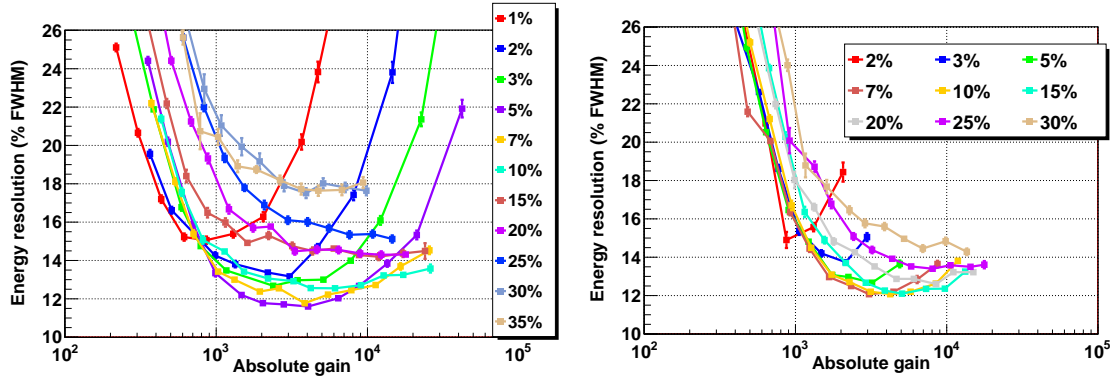


Figure 5: *Dependence of the energy resolution with the absolute gain for two detectors of 50 (left) and 25 μm -thickness-gap (right) in argon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.*

The results obtained for other quenchers are similar to the ones presented for argon-isobutane. We will just focus on the main differences. The first particularity (shown in figure 6) is that the plateau of maximum electron transmission is wider for mixtures with cyclohexane and narrower for ethane, in comparison to isobutane. The argon-ethane result is consistent with its higher diffusion coefficient for the same percentage of quencher [20]. In the case of cyclohexane, no data is available on its gas properties.

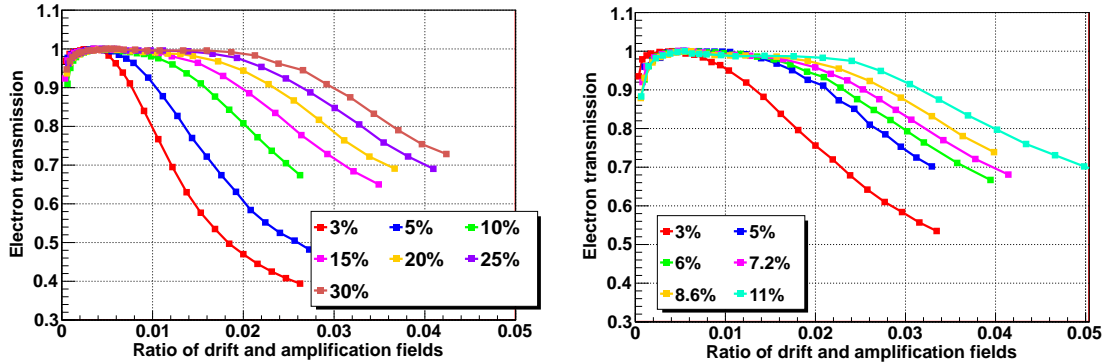


Figure 6: *Dependence of the electron transmission with the ratio of drift and amplification fields for a detector of 50 μm -thickness-gap in argon-ethane (left) and -cyclohexane mixtures (right). The gain has been normalized to the maximum of each series. The percentage of each series corresponds to the quencher concentration.*

As shown in figure 7, the maximum gain before the spark limit is respectively 2×10^4 and 4×10^4 for mixtures with ethane and cyclohexane and the 50 μm -thickness-gap detector. Only for cyclohexane, gains higher than in argon-isobutane mixtures are reached. We have also observed that the required voltage to reach the same gain is lower for cyclohexane, than for isobutane or ethane. For instance, an amplification field of 65 kV/cm must be applied to reach a gain of 10^4 in $\text{Ar}+5\%\text{iC}_4\text{H}_{10}$. This field is only 61 kV/cm in the case of cyclohexane and increases up to 72 kV/cm for ethane.

In table 1 we show the best values for the energy resolution obtained in each kind of mixture. We first note that the optimum performance of the 50 μm -thickness-gap microbulk is reached with quencher concentrations around 5%. For the gap of 25 μm , this percentage rises up to 10%. Nevertheless, the results are quite similar for all mixtures. From some measurements made with proportional counters in [10], it was concluded that

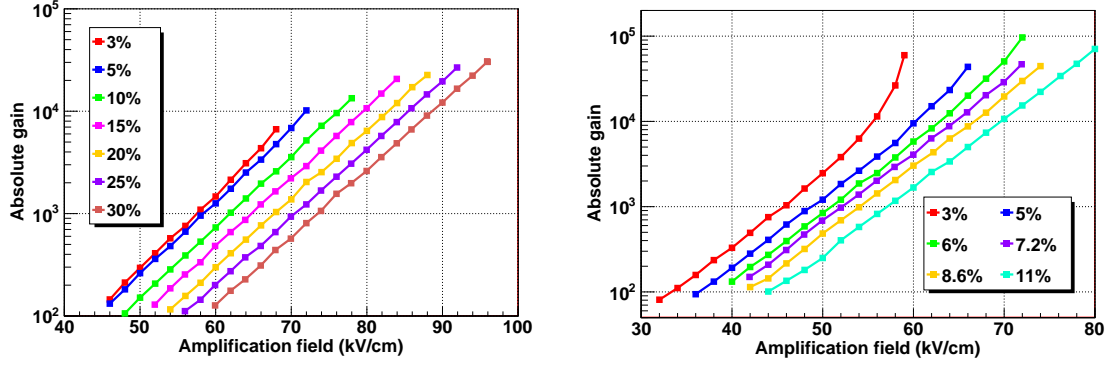


Figure 7: *Dependence of the absolute gain with the absolute gain for a detector of 50 μm -thickness-gap in mixtures of argon with ethane (left) and cyclohexane (right). The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the quencher concentration.*

quenchers whose ionization threshold were similar to the first metastable level of argon (11.5 eV) should show a higher gain and a better energy resolution. This improvement is related to a higher Penning effect [22], i.e., an energy transfer from the base gas atom to the quencher molecule, resulting in an increase of the avalanche ionization. However, this fact does not agree in the case of cyclohexane, as even if its ionization threshold (9.9 eV) is a bit low, the gain is higher with no degradation on the energy resolution.

Recent studies [21] support the main role of the non-metastable levels in Penning effect. Quenchers whose ionization threshold is lower than this level should show the same energy resolution. The higher gain observed in argon-cyclohexane mixtures could be related to a little contribution of argon excimers, created for energies between 8.9 and 10.3 eV.

Type of quencher	Ion. thres eV	50 μm gap		25 μm gap	
		Resolution % FWHM	Quencher %	Resolution % FWHM	Quencher %
Ethane	11.7	12.0	5 – 10	11.9	10 – 25
Isobutane	10.8	11.7	5 – 7	12.1	7 – 15
Cyclohexane	9.9	12.0	5 – 6	11.6	7.2 – 11

Table 1: *Best values of the energy resolution in mixtures of argon with ethane, isobutane and cyclohexane for two microbulk detectors with gaps of 50 and 25 μm . The range of quencher concentration for which these values are obtained is also shown. The systematic error of all values is 0.2% FWHM.*

We finally present in figure 8 the dependence of the energy resolution with the gain for the microbulk of 50 μm -thickness-gap in mixtures of argon with ethane and cyclohexane. The maximum gain before the spark limit is respectively 2×10^4 and 4×10^4 . Note that in the case of cyclohexane there is a clear degradation of the energy resolution at high gains, which is absent for ethane.

4 Neon-based mixtures for sub-keV applications

Micromegas detectors have been typically operated in argon-isobutane mixtures between 2 and 5% for a wide range of applications. This gas is well adapted for measurements in the 1-10 keV range, providing an excellent energy resolution and gains up to 2×10^4 . Other gas mixtures are being studied to increase micromegas sensitivity in the sub-keV region. For this purpose, the signal to noise ratio must be increased and higher gains are needed, keeping a good energy resolution. A possible solution is the replacement of the base gas by neon, as the total charge per single avalanche is increased and approaches the Rather limit ($\approx 10^8$ electrons). However, the efficiency of the photon absorption is lower in this kind of mixtures, passing from 70% down

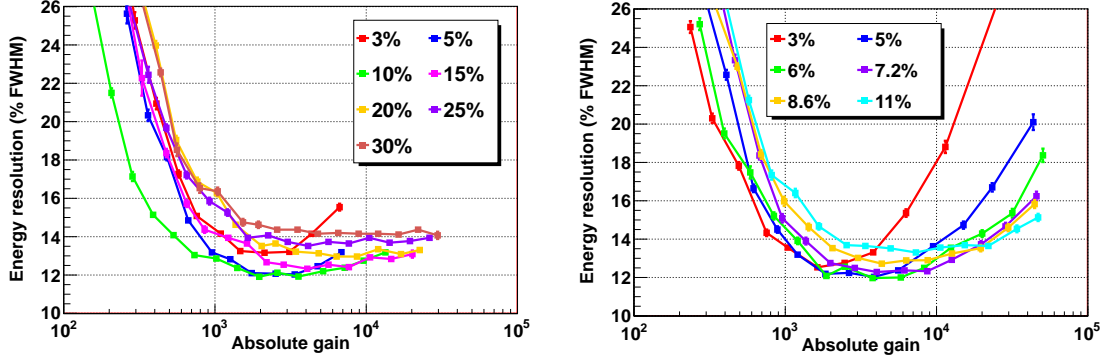


Figure 8: *Dependence of the energy resolution with the absolute gain for a detector of 50 μm -thickness-gap in argon-ethane (left) and -cyclohexane mixtures (right). The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the quencher concentration.*

to 10% at 6 keV, which limits the range of applications. We present the main features of the two detectors studied in neon mixtures with the same quenchers used before (isobutane, cyclohexane and ethane).

The electron transmission curves of both detectors show the same features observed in argon-based mixtures. For the case of the 50 μm -thickness gap, the plateau of maximum mesh transparency widens as the quencher concentration is increased, as shown in figure 9 (left) for isobutane, and the energy resolution is correlated to this variable (same figure, right). The plateau is absent for the other detector but there is a narrow range of fields for which the energy resolution reaches its best values. Comparing their performances to argon-based mixtures, we have observed narrower plateaus of maximum transmission for the gap of 50 μm , which can be explained by the higher diffusion coefficients in neon [20].

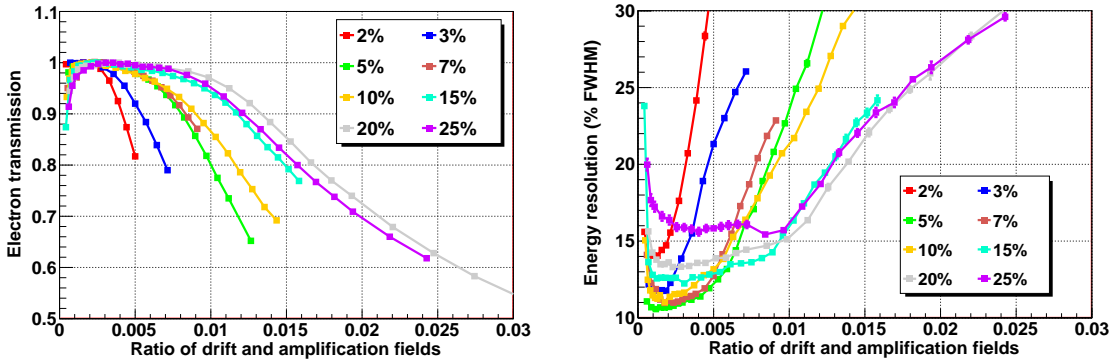


Figure 9: *Dependence of the electron transmission (left) and the energy resolution (right) with the ratio of drift and amplification fields for a microbulk detector of 50 μm -thickness gap in neon-isobutane mixtures. The gain has been normalized to the maximum of each series. The percentage of each series corresponds to the isobutane concentration.*

The dependence of the absolute gain with the amplification field is shown in figure 10. Gains higher than 5×10^4 and 2×10^4 are respectively reached for isobutane concentrations greater than 7 and 10% and for a gap of 50 and 25 μm . Moreover, the required field for a fixed gain does not increase with the quencher concentrations below 10%, as in argon-based mixtures. We will try to interpret this difference in terms of gas properties in the next section. A second fact observed is that higher fields are needed in these mixtures to get the same gain. As an example, a field of 72 kV/cm must be applied in Ar+10% iC₄H₁₀ to reach a gain of 10^4 for the detector of 50 μm -thickness gap. In a neon based mixture, this value is 75 kV/cm. This difference is greater for the other detector: respectively 140 kV/cm and 167 kV/cm for the same mixtures.

An improvement in the energy resolution has been observed for neon-based mixtures and the 50 μm -

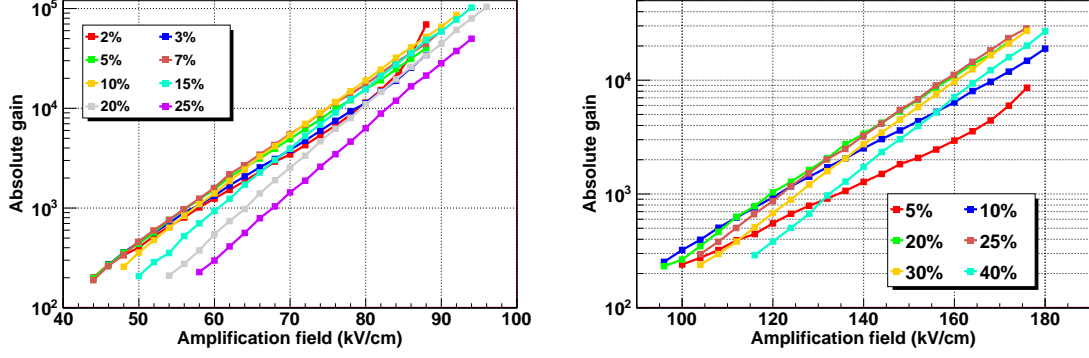


Figure 10: *Dependence of the absolute gain with the amplification field for two microbulk detectors with gaps of 50 (left) and 25 μm (right) in neon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.*

thickness-gap detector, going from 11.7% FWHM for Ar+5% iC_4H_{10} down to 10.5% FWHM for Ne+7% iC_4H_{10} . This fact cannot be explained by the fluctuations of the primary ionization but by the contribution of the detector avalanches. As described in [23], the energy resolution of the detector can be expressed as

$$R(\% \text{ FWHM}) = 2.35 \sqrt{\frac{W}{E_0}} (F + b) \quad (1)$$

where E_0 is the event energy, F is the gas Fano Factor, W is the mean energy necessary for creating an electron-ion pair in the gas and b is the detector contribution. In neon-based mixtures, less primary electrons are generated due to its higher mean electron-ion pair energy (respectively 36.4 and 26.3 eV for neon and argon [23]), which should worsen the energy resolution as the Fano factor is similar to both gases (0.17 [24]). The detector contribution must be thus little for neon-based mixtures. In fact, as noted in [17], less avalanche fluctuations are presented in light gases like helium or neon due to their higher ionization yield.

The energy resolution is also better at high gains, as shown in figure 11 (left). At a gain of 5×10^4 , the energy resolution is 11.4% FWHM in Ne+10% iC_4H_{10} , better than the 15% FWHM reached in Ar+11% cyclohexane. Similar values are also obtained with ethane or cyclohexane, as shown in table 2, which may point out that it is mainly determined by the base gas.

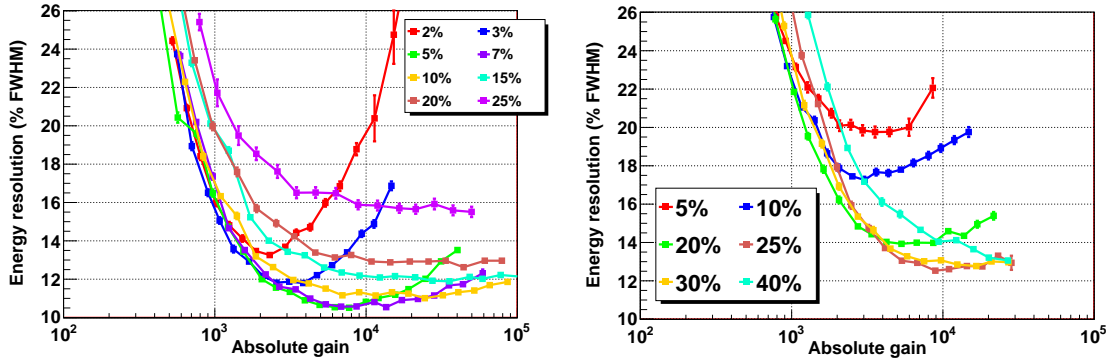


Figure 11: *Dependence of the energy resolution with the absolute gain for two detectors of 50 (left) and 25 μm -thickness-gap (right) in neon-isobutane mixtures. The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the isobutane concentration.*

In contrast, the energy resolution is worse in neon-based mixtures for the 25 μm -thickness-gap detector, passing from 11.6% FWHM in Ar+10% iC_4H_{10} to 12.6% FWHM in Ne+25% iC_4H_{10} . Worse values have also been obtained with the other quenchers, as shown in table 2. Larger amplification gaps are in principle

more adequate for light gases as they minimize the avalanche fluctuations produced by gap uniformities [11]. Another possible explanation is a small energy transfer between neon and the quencher due to the gap size [12], which may limit the Penning effect.

Type of quencher	Ion. thres eV	50 μm gap		25 μm gap	
		Resolution % FWHM	Quencher %	Resolution % FWHM	Quencher %
Ethane	11.7	10.7	5 – 15	14.8	25
Isobutane	10.8	10.5	5 – 7	12.6	25 – 30
Cyclohexane	9.9	10.6	8 – 10	16.6	10

Table 2: *Best values of the energy resolution in mixtures of neon with ethane, isobutane and cyclohexane for two microbulk detectors with gaps of 50 and 25 μm . The range of quencher concentration for which these values are obtained is also shown. The systematic error of all values is 0.2% FWHM.*

We finally present in figure 12 the dependence of the energy resolution with the gain for the microbulk of 50 μm gap in mixtures of neon with ethane and cyclohexane. The maximum gain before the spark limit is respectively 5×10^4 and 10^5 . In contrast to argon-based mixtures, there is no degradation of the energy resolution at high gains.

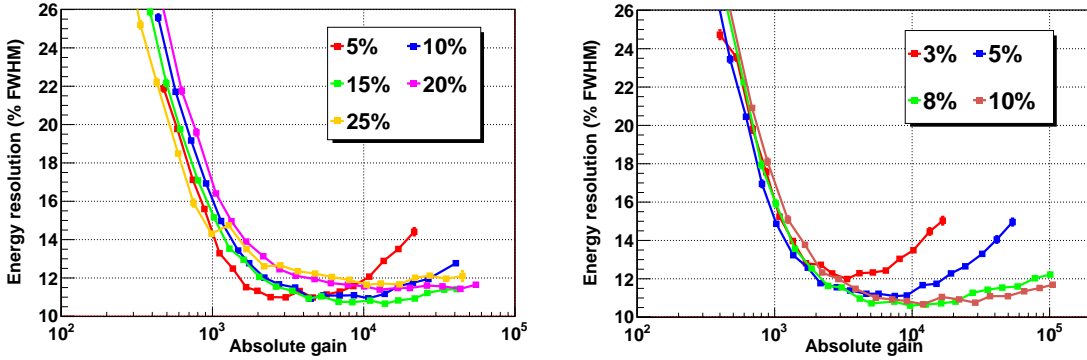


Figure 12: *Dependence of the energy resolution with the absolute gain for a detector of 50 μm -thickness-gap in neon-ethane (left) and -cyclohexane mixtures (right). The maximum gain of each curve was obtained just before the spark limit. The percentage of each series corresponds to the quencher concentration.*

5 Micromegas and the Rose-Korff gain model

The Rose-Korff model is a parametrization of the first Townsend coefficient which neglects the possible secondary ionizations in the avalanche [18]. If we modelize Micromegas as a parallel-plate detector and we suppose that the amplification field is uniform, the gain can be expressed by the formula

$$\ln(G) = \frac{d}{\lambda} \exp\left(\frac{-I_e}{\lambda E_{amp}}\right) \quad (2)$$

where G is the gain, E_{amp} is the amplification field, d is the gap distance, λ is the electron mean free path and I_e is the threshold energy for ionization. Therefore, this simple model can give information on gap properties. This study was firstly made in [25]. The gain curves generated in argon- and neon-based mixtures have been fitted to the equation 2 and the resulting dependencies of the electron mean free path and the threshold energy for ionization are respectively shown in figures 13 and 15.

As shown in figure 13, the electron mean free path decreases as the quencher concentration is increased and, for the same base gas and detector, there is almost no difference for low quencher quantities. At

high concentration, mixtures with ethane show higher values than with isobutane. Apart from that, neon-based mixtures show higher values than in argon-based ones. For instance, the electron mean free path is respectively 1.6 and 2.5 μm in $\text{Ar}+5\%\text{iC}_4\text{H}_{10}$ and $\text{Ne}+5\%\text{iC}_4\text{H}_{10}$ for the 50 μm -thickness-gap detector. These three facts can be explained by theory [23], even if the exact values do not match. The electron mean free path is in general higher for light gases, for noble gases in comparison to hydrocarbons and for ethane compared to isobutane. Finally, we have also observed lower values for the gap size of 25 μm , which cannot be explained by gas properties.

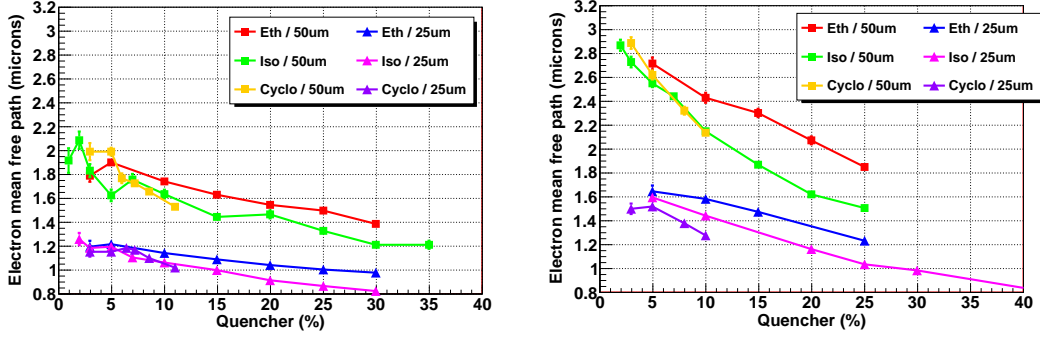


Figure 13: *Dependence of the electron mean free path with the quencher concentration for the argon- (left) and neon-based (right) mixtures studied. Values have a relative systematic error of 10%.*

To confirm experimentally that the electron mean free path is shorter for heavier gases, we have revisited the gain curves generated for xenon-based mixtures in [27]. The electron mean free path (figure 14, left) is clearly lower than in other gases, as xenon is a heavier gas. Small differences are due to higher systematic errors in the gain measurements.

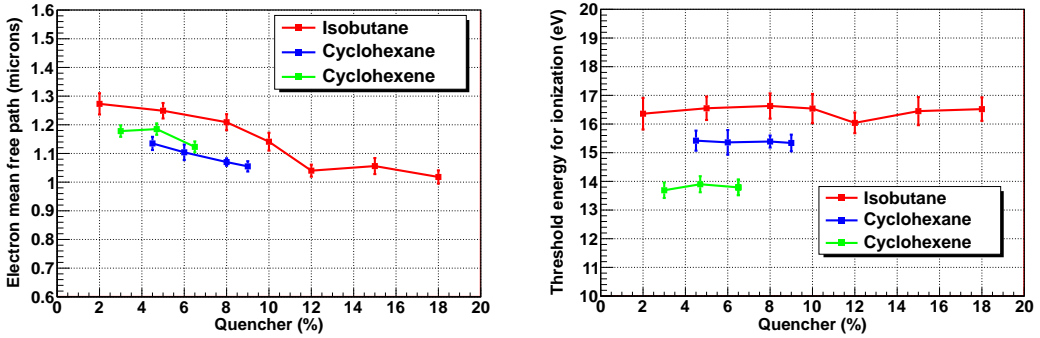


Figure 14: *Dependence of the electron mean free path (left) and the energy threshold for ionization (right) with the quencher concentration for different xenon-based mixtures generated by the first micromegas detectors with a gap of 50 μm [27]. Values have a relative systematic error of 20%.*

The energy threshold for ionization has a different behaviour in argon- than in neon-based mixtures, as shown in figure 15. For the first type, this parameter increases with the quencher quantity and is independent of the gap size. For example, for a quencher percentage of 10%, the energy threshold is respectively 15.2, 14.3 and 13.5 eV for ethane, isobutane and cyclohexane. In contrast, this parameter shows a minimum in neon-based mixtures, which depends on both the quencher and the detector. For all mixtures, values are higher for a gap size of 25 μm .

These differences can be explained by the Penning effect. The transfer of energy from non-metastable levels of argon to the quencher molecule is complete for both detectors in argon-based mixtures and the energy threshold is only defined by the quencher. For neon, as the electron mean free path is longer, the

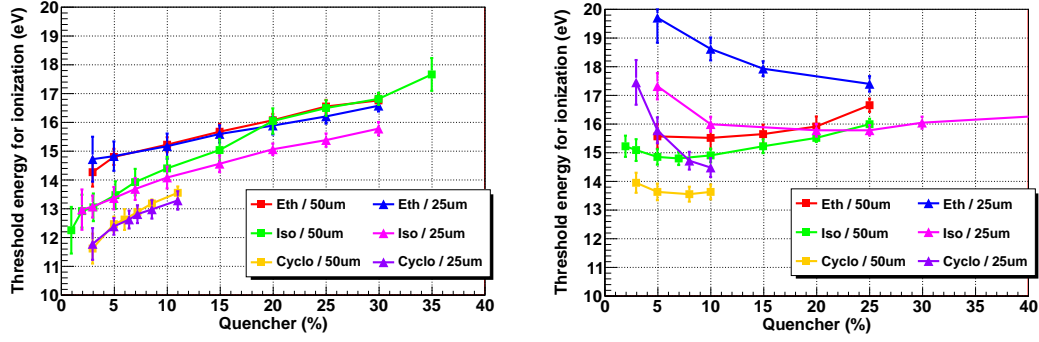


Figure 15: *Dependence of the energy threshold for ionization with the quencher concentration for the argon-based (left) and neon-based (right) mixtures studied. Values have a systematic error of 10%.*

transfer is limited by the gap size. This limitation disappears at high quencher quantities and the energy threshold for ionization increases with quencher concentration, as in argon-based mixtures.

Finally, the values obtained in neon are in general higher than in argon-based mixtures. For example, this parameter is respectively 15.6 and 14.8 eV in Ne+5% ethane and Ar+5% ethane for the 50 μm -thickness-gap detector. This fact is due to the higher values of this parameter for pure neon (21.6 eV) than for pure argon (15.8 eV) [23]. Note that the values given in literature for the base gases and for the quenchers (11.7 and 10.8 eV for ethane and isobutane) do not match with the ones obtained. As discussed in [25, 26], this fact can be explained by the Penning effect [22], which is quite important in mixtures with big differences between the ionization threshold of the quencher and the excitation levels of the base gas.

A good question is if the values obtained for the electron mean free path and the energy threshold for ionization could explain the energy resolution of a detector in a gas. We can start our discussion using [11], where it was concluded that the fluctuations due to defects of the mesh and the gap flatness could be compensated choosing the idoneous gap for each gas type. This optimum was obtained by differentiating the equation 2, which results in

$$\frac{\delta G}{G} = G \left(1 - \frac{d I_e}{\lambda V_{amp}} \right) \frac{\delta d}{d} = 0 \Rightarrow E_{amp}^{opt} = \frac{I_e}{\lambda} \quad (3)$$

We can interpret this minimum in terms of an optimum amplification field for a fixed gap. For each gas, this field should be as low as possible to fastly reach an optimum detector performance and to avoid the degradation of the energy resolution by other effects. Therefore, the electron mean free path should be as high as possible and the values of the energy threshold for ionization should be little.

As shown in figures 13 and 14 (right), the first parameter is mainly determined by the base gas, being higher for neon than for argon or xenon. The quencher concentration decreases its value, which in general degrades the energy resolution. There is also a dependence on the gap size, as lower values are obtained for a gap of 25 μm . As we have shown, the gap size is only important in neon-based mixtures. In the case of the energy threshold for ionization, we have observed lower values for cyclohexane than for isobutane and ethane but there is no clear improvement in the energy resolution. This variable could have thus little effect if the optimum amplification field is in the working range.

6 Conclusions and perspectives

Microbulk is a Micromegas technology that has been used in nuclear (nTOF) and astroparticles experiments (CAST, NEXT). It offers uniform and flexible structures with an excellent energy and time resolution, low background levels and low mass. Two detectors, with a gap distance of respectively 50 and 25 μm , have been characterized in argon-based mixtures with ethane, isobutane and cyclohexane, using a ^{55}Fe source. The maximum gain before the spark limit is respectively 2×10^4 and 10^4 and the best energy resolutions obtained in argon-isobutane mixtures are 11.7% and 12.1% FWHM at 5.9 keV. The plateau of maximum

electron transmission depends on the quantity of quencher for the 50 μm -thick-gap detector and is almost inexistent for the gap of 25 μm . The same conclusions have been obtained with the other quenchers but the gain is higher in argon-cyclohexane mixtures and lower with ethane.

Microbulk detectors have been also tested in neon-based mixtures with the same quenchers to reduce the energy threshold and to make Micromegas sensitive to sub-keV energies. Possible applications are synchrotron radiation and Dark Matter searches. The maximum gain reached before the spark limit in argon-isobutane mixtures is respectively 5×10^4 and 10^5 for a gap size of 25 and 50 μm and the best energy resolutions are 10.5% and 12.6% FWHM at 5.9 keV. Similar values for the energy resolution have been obtained with the other quenchers except for the detector of 25 μm -thickness gap and neon-based mixtures, whose values are worse.

The last developments of microbulk technology are focused in creating detectors with small gaps (12.5 and 25 μm) to be used with gases at high pressure. Different hole pitches and diameters are being studied. The use of other quenchers with even lower ionization threshold like cyclohexene are also planned, in order to confirm the divergences observed in argon-cyclohexane between micromegas detectors and proportional counters.

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